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Descriptive Analysis of Information Transfer in Human Brain

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This paper provides a descriptive analysis for the results of a measuring tool called transfer entropy, in quantifying the amount of information transported to different brain sites in two conditions: eyes closed and resting, and eyes open and resting. Directional flow of information transfer is also examined.

1. INTRODUCTION

The human brain is a system that has not been fully understood. In the human anatomy, the brain is considered a highly complex organ [1]. It exhibits electrical activity that is much influenced by its functions. By placing electrodes on the scalp for instance, it is possible to record its activity in a technique known as electroencephalography (EEG) [2]. The signals taken provide a way of evaluating the dynamics associated with routine brain functions especially in our primary senses.

A lot of resources is taken up in the brain because of vision [3]. With the eyes open, segregated brain regions tend to work together in processing information gathered by the eyes to have coherent cognitive perception of our surroundings. This integration among brain regions narrow us down to the idea on effective connectivity. Since brain functions are constrained by connectivity, it is important to understand something about the causal relationships of this connectivity [4]. One way is by applying time series analysis to brain signal recordings. Measures used in time series analysis include investigating patterns of information transfer through quantifying information flow rate and determining directed exchange of information between brain regions. As far as we know, this is the first comparative study on the patterns of information transfer in human EEG using transfer entropy under two behavioral conditions: eyes closed and eyes open. A fixed bin size of two hundred thirty (230) is used in the adaptive binning. It is hoped that by obtaining transfer entropy, we can extract the behavior of the brain, specifically the dynamics of information pathways while undergoing these states.

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2. Transfer Entropy

In dealing with information transfer, one seeks a functional relationships or measures of correlation or of causal relations. In the case of causal relationship, the measure of information transfer is expressed in terms of transfer entropy [4]. Such a measure is defined by Schreiber [5], and which is illustrated as follows.

Suppose given a series of simultaneously measured values of two variables $X = \{x_1, x_2, \cdots, x_N\}$ and $Y = \{y_1, y_2, \cdots, y_N\}$ of the same system, Schreiber's transfer entropy is defined as

$$T_{Y\to X} = \sum_k p(x_{k+1}, x_k, y_k) log_2 \frac{p(x_{k+1}|x_k, y_k)}{p(x_{k+1}|x_k)} \tag{1}$$

where expressions of $p(x|y)$ are conditional probabilities. Equation (1) quantifies the causality of information transfer between X and Y. It is a kind of information measure that represents the flow of information between stochastic variables.

Now, since conditional probabilities are much harder to solve, its equivalent joint probabilities are used, thus, expressing equation (1) into

$$T_{Y\to X} = \sum_k p(x_{k+1}, x_k, y_k) log_2 \frac{p(x_{k+1}, x_k, y_k)p(x_k)}{p(x_k, y_k)p(x_{k+1}, x_k)} \tag{2}$$

Equation (2) has an inherent asymmetric property in that it measures the degree of dependence of X on Y, and not vice versa. So that is the transfer entropy $T_{X \to Y}$. Directional flow of information can then be determined by calculating net transfer entropy ΔT which is given by,

$$\Delta T = T_{Y \to X} - T_{X \to Y} \qquad (3)$$

A negative value of ΔT, for instance, would indicate that from the pairing of (sub)systems, Y is much more dependent on the information transported from X rather than from Y to X [3]. The amount of information transfer is expressed in units of bits.

3. Multichannel EEG data

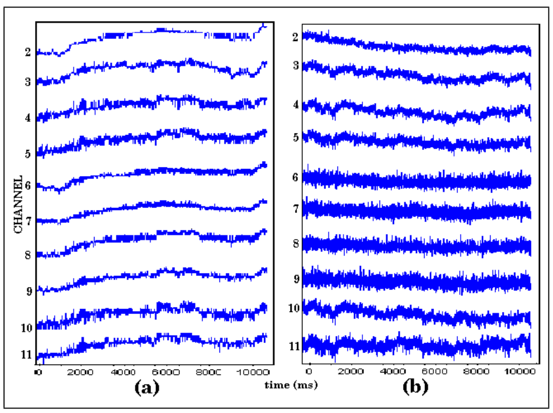

Figure 1. Raw EEG signals from subject 1. (a) EEG signals from eyes closed and resting condition. (b) EEG signals from eyes open and resting condition.

To explore the causal relationships, 10-channel, free-running EEG signals from 11 healthy adults are used. EEG signals are records of voltages from different scalp sites [6]. These multichannel records were obtained in two behavioral conditions: eyes closed, resting and eyes open, resting. And since physical pattern of anatomical connections is relatively stable at shorter time scales, each data file was taken no more than twelve seconds long. But the actual analyses have used clean 10500 point subepochs. For instance, EEG signals from subject 1 is shown in Figure 1. These signals represent records of voltages measured at the scalp locations shown in Figure 2. Visual inspection on these plots reveals that there is really a distinct signature between EEG signals for eyes closed (Figure 1(a)) and eyes open conditions (Figure1(b)). Eyes open condition shows more erratic signals compared to eyes closed condition.

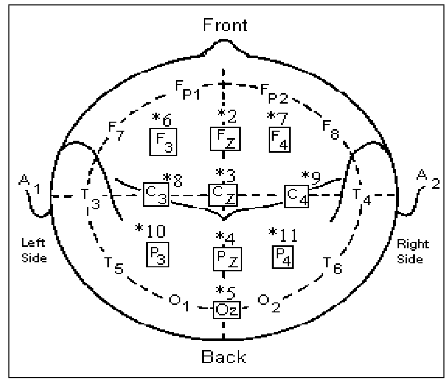

Figure 2. Top view of the human head, shows the actual electrode placement following the so-called 10-20 system [2].

The letters (F,T,P,O) in Figure 2 stand for the different lobes of the brain (frontal, temporal, parietal, occipital) and the numbers are identifiers for the two brain hemispheres (1,3,5,7 are for the left hemisphere and 2,4,6,8 are for the right hemisphere) [2]. These locations are labeled with channel numbers as shown in the figure. Only the EEG signals recorded from the boxed locations indicated in the same figure are considered in this study.

4. Algorithm Implementation

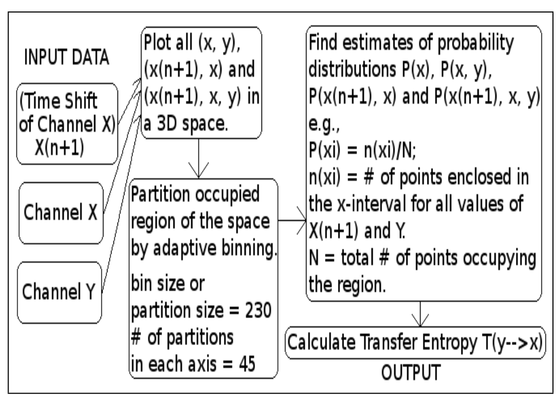

Figure 3. Schematic diagram of the process in calculating transfer entropy.

The computational tool used in the analysis is Scilab [7]. For every human subject, combinations of all possible channel pairs are made. Scilab calculates the transfer entropy for every pair using the schematic diagram of the algorithm indicated in Figure 3. Results of transfer entropy are then averaged over all channel pairs and over all subjects.

5. RESULTS AND DISCUSSIONS

Results of the average net transfer entropy are shown in single line plots in Figure 4.

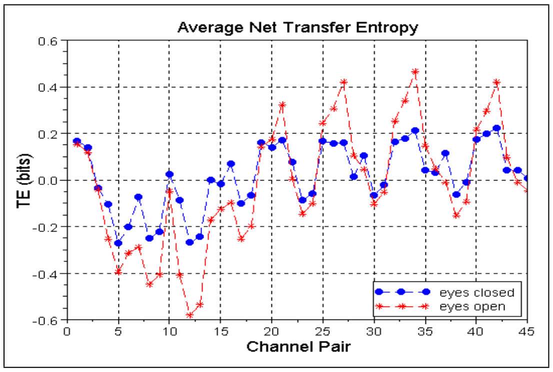

Figure 4. Single line plots of the net transfer entropy averaged over all subjects.

From the figure, it is shown that for eyes closed condition, net transfer entropy oscillates in the range [-0.27,0.22] bits with a mean value of 0.015 bits. Whereas for the eyes open condition the corresponding values are [-0.58,0.46] and -0.02 respectively. For the largest values of this measurement in eyes open condition, it is found out that the standard deviation nearly doubles that of the eyes closed condition. This only means significant amount of information has been transferred among brain regions when an individual sees. Among these largest values of information transfer in open eyes condition relative to its corresponding values in eyes closed condition are the channel pairs 4, 5, 8, 9, 12, 13, 27, 34 and 42. With these pairs, it is evident that F4, F3, Oz (shown in Figure 2) are the prominent regions exhibiting seemingly active communication to many other regions. This is consistent with the established known functions of these brain regions; the frontal lobe is mainly for cognitive functions (awareness, attention, etc.) and the occipital lobe is where conscious processing of visual inputs takes place [8].

It is also remarkable that some of the channel pairs show values that are negligible to zero in both conditions but exhibit significant amount of transfer entropy in its corresponding counterpart condition. These channel pairs with directional flow are 22, 37 and 44 for eyes open condition and 14, 15, 28, and 45 for eyes closed.

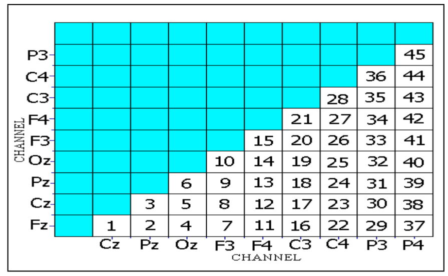

Figure 5. The numbers in each cell identify the channel pairs (shown in Figure 4) corresponding to the location of information transfer.

Taking channel pair 22 as an example, the flow of information is from Fz to C4. When one sees, this particular pair seems to show no connectivity between them but resumes connection or information transfer once the eyes are closed.

Relatively comparable activity in both conditions are also noticeable for channel pairs 1, 2, 3, 19 and 36. This means that no significant changes in the amount of information tranfer are made for both conditions. These findings may link to the activation of associative cortical regions of the brain that are also involved in processing visual information and the establishment of visual memories [8].

6. Summary

This research is a work in progress but preliminary results show that overall, transfer entropy in eyes open condition are thus, far greater than in the eyes closed condition. And for the other findings, it is still too early to have concluding remarks.

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